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RESEARCH MEMORANDUM

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The RAND Corporation
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QUICK KEY Report No. 4
(ARPA Order 11-59)
AF-49(638)-500

RESEARCH MEMORANDUM

A SURVEY OF CURRENT RESEARCH
IN GASEOUS ELECTRONICS
IN THE UNITED STATES (U)

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RM-2310-ARPA

January 7, 1959

Assigned to ______________________

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SUMMARY

This memorandum outlines the relation of atomic and ionic impact phenomena to the propagation of electromagnetic waves in the upper atmosphere. Several group efforts are described which are aimed at stimulating research on impact phenomena and related fields in Gaseous Electronics. Descriptions are given of current and projected research in principal laboratories in the United States. The status of the research is summarized and suggestions for further research are presented.

FOREWORD

This memorandum reports on certain unclassified activities of Project QUICK KEY, carried on by the RAND Corporation for the Advanced Research Projects Agency from August 1958 to January 1959. QUICK KEY was established by ARPA Order 11-59, under Contract AF 49(638)-500 with the Air Force Office of Scientific Research, to conduct an information center concerned with various aspects of the physics of the upper atmosphere. Among the subjects of interest were the reactions among electrons and other upper-atmosphere constituents, particularly in regard to the effect of these reactions on electromagnetic wave propagation. In pursuit of this interest a survey of United States research activities in the field of Gaseous Electronics was undertaken, the results of which are described in the present memorandum. It is hoped the information presented here will be useful to those who may have some role in planning future research and in the allocation of research funds and time.

Another unclassified QUICK KEY memorandum deals with information about the IGY programs pertaining to the upper atmosphere.

Inquiries concerning distribution of these memorandums, or other QUICK KEY activities, should be addressed to ARPA.

Paul Tamarkin

Paul Tamarkin
Project Leader
Project QUICK KEY

ACKNOWLEDGMENTS

This memorandum was compiled with the cooperation of all those whose work is listed. The contribution of R. Geballe (University of Washington) was aided by support from the Office of Ordnance Research of the U. S. Army. The authors also wish to express their appreciation to Dr. R. L. Kirkwood of The RAND Corporation, for his assistance.

CONTENTS

I. INTRODUCTION

This memorandum presents a brief summary of the current status of research in Gaseous Electronics in the United States. In addition, basic areas are indicated in which additional data would be welcomed by research workers.

The operation of electromagnetic systems in and above the ionosphere has revealed a need for more detailed knowledge of fundamental processes that take place among constituents of the upper atmosphere under unusual conditions of excitation. All the areas in which knowledge and data will be required cannot be predicted, but it is certain that future technological developments, particularly some of military significance, will continue to require basic knowledge of our atmospheric environment.

For example, it is important to understand all ionospheric factors affecting electromagnetic systems during and after high altitude nuclear detonations. Electron collision frequencies and processes affecting electron density (processes for ionization of atmospheric species and for depletion of the ionospheric electron concentration) determine the ionospheric dielectric constant, and are thus of primary importance. However, information about the atmosphere even under normal conditions is scarce.

The general problems outlined above require information about interactions among atoms, molecules, ions, electrons, and photons in an energy range extending from tenths of an electron volt to perhaps a million electron volts. Interactions of interest include elastic impact, excitation, ionization, recombination, attachment and others. Experimental studies of such processes have been carried out by direct laboratory investigation of single encounters, and by attention to complex phenomena such as electrical breakdown of gases and ionospheric manifestations. The last of these, of course, requires many special techniques. Somewhat arbitrarily, the term "Gaseous Electronics" has come to designate laboratory investigations and related theoretical work in the pertinent areas, and the term is so used in the present report.

Several months ago it became apparent to a number of government agencies that a concerted attempt should be made to stimulate increased research into the properties of atmospheric gases under various conditions of excitation. The initial moves have taken the form of surveys of the existing state of such research in the United States. Among several independent approaches, three may be mentioned here: 1) During the summer of 1958 the Office of Ordnance Research of the U.S. Army sponsored visits by two scientists to a number of research establishments. Their list of pertinent research areas is included in Section III of the present report. 2) A conference held at Convair, San Diego, in August 1958 explored the status of relevant research fields, and gaps in experimental and theoretical knowledge were pointed out.* 3) The Advanced Research Projects Agency (ARPA), through Project QUICK KEY, has also arranged to gather and collate existing information on pertinent present and projected research in Gaseous Electronics.

Material for the present report was obtained from visits to research centers, from attendance at scientific meetings, from informal discussions and from letters solicited for this special purpose. An attempt was made to reach all possible workers now active in pertinent lines of research.

*This conference will be reported as the Proceedings of the Symposium on Molecular Interactions Induced by Nuclear Explosions in the Atmosphere, (Secret-Restricted Data), to be published by Convair, San Diego.

Without doubt important omissions occur; they are unintentional and the apologies of the authors are extended to any worker who was not included.

The remainder of this report consists of two sections and an appendix. Section II presents brief summaries of current activities in principal laboratories. In Section III the status of the work is summarized and suggestions for further research are presented. In the Appendix are presented more detailed descriptions of some of the current research activity, with references to published articles and reports.

II. SUMMARIES OF CURRENT ACTIVITIES IN GASEOUS ELECTRONICS

This section consists of brief descriptions of work recently completed, now in progress, and projected for the future. More complete discussions of some of these projects are given in the Appendix.

AIR FORCE CAMBRIDGE RESEARCH CENTER - Dr. O. Oldenberg

In progress:

Experimental study of inelastic collisions of protons in N_2 at energies of 10's of ev.

Projected:

Experimental study of collisions of fast neutral H atoms with H_2; also other pairs of colliding heavy particles.

UNIVERSITY OF ARKANSAS - Professors C. Y. Fan and Raymond Hughes

Completed:

(a) Experimental studies of the emission spectra of air excited by the impact of electrons, protons, and He^+ ions.

(b) Theoretical work related to charge exchange collisions.

Projected:

Spectroscopic studies of O_2 and N_2 bombarded by protons of energies up to 400 kev.

AVCO RESEARCH LABORATORY, Everett, Massachusetts - Dr. S. C. Lin

Completed or in progress:

Shock tube measurements of spectral emissivity and electromagnetic properties of air at high temperatures. Rates of dissociation, ionization, and photoexcitation behind strong shock fronts. Atom-atom and electron-ion recombination rates in high temperature air and other gases.

BELL TELEPHONE LABORATORY, Murray Hill, New Jersey - Dr. B. T. McClure

In progress or complete:

Experimental study of the number of ions created by electron collision in a field-free region in Neon and Neon + Argon at energies up to 200 ev.

Projected:

Extension to N_2.

UNIVERSITY OF CALIFORNIA - Professor Leonard Loeb

Completed:

His work on electrical discharges and negative ions is no longer active.
Correction: see page 8A

CONVAIR, San Diego - Dr. Roy Neynaber

Projected:

Use of a molecular beam to measure electron scattering cross sections with N, N_2, O, and O_2 for energies up to 10 volts.

Survey of atmospheric molecular collision processes with particular emphasis on those induced by a nuclear detonation or a hypersonic vehicle.

UNIVERSITY OF FLORIDA, Gainesville, Florida - Professors E. E. Muschlitz, Jr., T. L. Bailey, and W. H. Cramer

In progress:

(a) Scattering of low energy negative ions in gases, measurement of elastic and electron attachment cross sections in the energy range 4 to 400 ev.

(b) Elastic and inelastic scattering of beams of low energy (from a few ev to a few hundred ev) positive ions in gases at low pressures.

Projected:

(a) Extension of the work indicated above.

(b) Studies of negative ion formation by electron bombardment of gases.

GENERAL ATOMIC, San Diego

Group under Dr. Wade Fite

In progress:

Experimental studies of elastic and inelastic collision largely in

ACTIVITIES OF THE GASEOUS ELECTRONICS RESEARCH GROUP

Group under Professor L. B. Loeb
Department of Physics
University of California

Recent work accomplished in Professor Loeb's laboratories has included studies of the kinetic ejection of electrons from tungsten by cesium and by lithium ions, of the photoelectric effect from borosilicate glass, the nature and role of ionizing potential space waves in glow-to-arc transitions, and streamer sparks in air. Publications covering these studies are:

P. M. Waters, 'Kinetic Ejection of Electrons from Tungsten by Cesium Ions,' Phys. Rev., 109, 1466-1467 (1958).

P. M. Waters, 'Kinetic Ejection of Electrons from Tungsten by Cesium and Lithium Ions,' Phys. Rev., 111, 1053-1061 (1958).

V. K. Rohatgi, 'Photoelectric Effect from Borosilicate Glass,' Jour. Appl. Phys., 28, 951-959 (1957).

R. G. Westberg, 'Nature and Role of Ionizing Potential Space Waves in Glow-to-Arc Transitions,' to appear in April 1, 1959 issue of Phys. Rev.

In addition, Professor Loeb has written the following papers:

'Mechanism of Cataphoretic Segregation in Inert Gas Glow Discharges,' Jour. Appl. Phys., 29, 1369-1371 (1958).

'Significance of Formative Time Lags in Gaseous Breakdown,' Phys. Rev., 113, 7-12 (1959).

He has also read the proofs of his book, Static Electrification, published in English from the press of J. Springer and Company, West Berlin, Germany, 1958. He has prepared for distribution (May 1959) to an ONR distribution list and to other agencies, a mimeographed appendix to the second printing of Basic Processes of Gaseous Electronics. This appendix deals with advances in gaseous electronics since 1955 and contains an extensive bibliography.

Currently in progress in Professor Loeb's laboratories are the following subjects:

Initiation of the filamentary streamer spark in pure argon by an anode streamer. Gas cataphoresis is being used to remove trace gases of lower ionizing potential.

Fast oscilloscopic time analysis of transient breakdown of argon in an all-glass cell with external electrodes and with a steady or very low frequency (60 cycle) alternating potential. The study will be extended to photosensitive Penning gases.

Investigating the surface conductivity of electrons plastered onto a borosilicate glass surface in high vacuum. The purpose of the investigation is to attempt to ascertain whether electrons in such surface states have an exceptionally high mobility.

Observations of the movement of the light pulse accompanying the spread of a Geiger counter along the anode wire in an air counter. A photomultiplier triggered by the rise of the ionizing pulse at one end has been used. A two-photomultiplier technique is being developed.

The laboratory plans to investigate basic processes in halogen-filled inert gas Geiger counter tubes with SnCl cathodes, using the Lauer-Huber techniques.

ground state hydrogen but some in oxygen, using beam techniques.

Projected:

Extension to electron collision with metastables, positive and negative ions, ionization by ions and other inelastic processes in hydrogen and oxygen.

Group under Dr. V. Van Lint

In progress:

Rates of electron recombination and attachment in atmospheric gases following irradiation by high energy electrons.

Dr. Edward Gerjuoy

Completed work:

(a) Theoretical studies of low energy elastic and inelastic collisions in molecular gases.

(b) Formal treatment of low energy scattering processes.

GENERAL ELECTRIC COMPANY, MISSILES AND ORDNANCE SYSTEMS DEPARTMENT, Philadelphia 24 - Dr. R. G. Breene, Jr.

Continuing·

Calculation of matrix elements between wave functions of free electron states and bound electron states in the presence of atoms.

Projected:

Calculation of wave functions of electrons in the fields of diatomic molecules.

GEORGIA TECH. - Professor Earl McDaniel

Completed:

Low field ion mobilities of negative ions in oxygen and other gases.

In progress and projected:

Studying reactions between thermal ions and gas molecules in a drift tube, using a mass spectrometer.

HARVARD UNIVERSITY - Dr. N. P. Carleton

In progress:

An experimental study of the spectra emitted by nitrogen after excitation by protons of a few kilovolts energy.

Projected:

Extension to lower energies and collisions of heavy atoms and ions with oxygen and nitrogen.

HUGHES AIRCRAFT COMPANY - Dr. Elsa Huber Solt

Completed and in progress:

(a) Studies of microwave propagation in ionized gases.

(b) Studies of electrical breakdown at microwave frequencies in O_2, N_2, He, Ne, A, and air.

Projected:

Extension of breakdown studies to halogen compounds.

UNIVERSITY OF ILLINOIS - Professor L. Goldstein

In progress:

Microwave transmission methods for measuring electron collision cross sections and robbing reactions in nitrogen and oxygen at temperatures down to 77°K.

Projected:

Mass analysis of ions present in the above experiment by measurements of cyclotron frequencies of the ions present.

JOHNS HOPKINS UNIVERSITY - Professor Donald E. Kerr

In progress:

Studies of recombination between electrons and helium molecular ions.

LOCKHEED, MISSILE SYSTEMS DIVISION, Palo Alto, California - Dr. R. E. Meyerott

In progress:

(a) Experimental studies of reactions involving molecular gases and their ions, using crossed beam techniques at energies down to 10 ev.

(b) Calculations of interactions between electromagnetic radiations and atmospheric gases, with reference to ionospheric processes.

Projected:

(a) Extension of the above work.

(b) Cross sections for excitation of oxygen and nitrogen by electron collision.

(c) The number and velocity distribution of secondary electrons produced by electron collisions in nitrogen and oxygen.

(d) The velocity distribution of the primary electrons after exciting and ionizing collisions in nitrogen and oxygen.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Boston - S. C. Brown

Completed:

His experimental work on the low energy collisions in atomic gases using microwave techniques is no longer active. Current activity is mainly in the study of highly ionized plasmas.

NATIONAL BUREAU OF STANDARDS - Group under Dr. L. M. Branscomb

Recently completed or in progress:

(a) Photodetachment of electrons from negative ions using beam techniques.

(b) Crossed beam measurement of inelastic electron scattering by negative ions.

(c) Experimental study of positive ion mobilities.

(d) Theoretical studies of low energy cross sections for photodetachment, collisional detachment by electrons, elastic scattering of electrons and positive ion mobilities.

Projected:

(a) Extensions of above.

(b) Electron excitation of several astrophysically pertinent spectral lines.

NAVAL RESEARCH LABORATORY - Philip Shapiro

Projected:

Measurement of the absorption and reflection of microwaves from highly ionized air and N_2 at low pressures.

NEW YORK UNIVERSITY, Washington Square Campus - Dr. Sidney Borowitz

In progress:

(a) Theoretical studies directed toward devising a simple technique for handling elastic and inelastic scattering problems.

(b) Theoretical studies directed toward devising a simple method for characterizing excited states (e.g. properties such as charge distribution).

NEW YORK UNIVERSITY, University Heights Campus

Professor L. H. Fisher

In progress:

Experimental studies of processes leading to breakdown in atomic and molecular gases at high pressure.

Projected:

Extension of this work.

Professor B. A. Bederson

In progress:

Experimental study of low energy elastic scattering of electrons from atoms using beam techniques.

Joint

In progress:

Application of magnetic resonance techniques to the experimental study of dissociation and ionization accompanying breakdown in gases.

OHIO STATE UNIVERSITY - Professor E. N. Lassettre

Completed:

(a) Differential scattering cross sections of electrons on atmospheric gases.

(b) Determination of atomic oscillator strengths from electron impact data.

Projected:

Refinement of the above experiments.

UNIVERSITY OF OKLAHOMA - Professors R. G. Fowler, P. Little, R. M. St. John, and Otto Theimer

In progress:

(a) Experimental studies of excitation cross sections of atoms for electron impact at energies from the excitation potential to a few hundred volts by detection of light emission.

(b) Experimental studies of plasmas in a shock tube.

(c) Theoretical work on the conductivity of a plasma and on the theory of the microfield in a plasma.

Projected:

(a) Extension of the above.

OREGON STATE COLLEGE - Professor D. S. Burch

Proposed:

Experimental study of photodissociation using EPR technique to measure cross section and possibly recombination coefficient.

UNIVERSITY OF PITTSBURGH - Professor T. M. Donahue

In progress:

Measurements of charge exchange cross section for protons in hydrogen.

Projected:

Extension of the above to D^+, He^+, He^{++}, Na^+, and O_2^+ in H_2, D_2, N_2, and air.

PROVIDENCE COLLEGE - Professor Morton A. Fineman

In progress:

Studies of negative ions formed by electron impact upon N_2 and CO in a Lozier apparatus.

Proposed:

Extension of the above to O_2 and NO.

UNIVERSITY OF SOUTHERN CALIFORNIA - Professor Gerhard L. Weissler

In progress:

(a) Experimental studies of photochemical reactions induced by radiation in the vacuum ultraviolet.

(b) Applications of mass spectrometry to experimental studies of photo-ionization in gases.

(c) Experimental studies of the feasibility of the vacuum ultraviolet as a tool for plasma **diagnostics**.

(d) Volume photoelectric effect induced by radiation in the vacuum ultraviolet.

Projected:

(a) Use of radiation from Townsend discharge as a source of photoionization.

(b) Extension of energy range to soft x-ray region.

STANFORD RESEARCH INSTITUTE - Group under Dr. C. J. Cook

In progress:

Experimental studies of ionization of molecular gases and their atoms by slow electrons using beam techniques.

Projected:

Extension to very low electron energies: new techniques for study of two-body reactions.

SYLVANIA, MICROWAVE PHYSICS LABORATORY, Mountain View, California - Group under Dr. R. M. Hill

In progress:

Experimental studies of elastic collision cross-sections for low energy electrons in helium and water vapor by measuring the widths of cyclotron resonance lines of free electrons in these gases.

Projected:

Extension to atmospheric and exhaust gases; measurement of fractional energy loss per collision.

UNIVERSITY OF TEXAS - Professor A. W. Straiton

In progress:

Measurement of the effects of gamma radiation on the refractive index of atmospheric gases.

UNIVERSITY OF WASHINGTON, Seattle

Professor R. Geballe

In progress:

(a) Experimental studies of attachment in molecular gases using mass spectrometric techniques.

(b) Experimental studies of ion-atom exchange reactions in molecular gases at low energy.

(c) Study of dissociative recombination in hydrogen by beam techniques.

Projected:

Extension of (c) to other molecular gases.

Professor K. C. Clark

In progress:

Experimental study of basic mechanisms in nitrogen afterglows using spectroscopic techniques.

WESTINGHOUSE RESEARCH LABORATORY, Pittsburgh, Pennsylvania - A group of about six under M. A. Biondi

In progress:

(a) Experimental studies of elastic and inelastic collision processes in molecular gases, with particular reference to electron attachment in oxygen. Swarm and beam techniques are used.

(b) Experimental studies of electron drift velocities at low energy in molecular gases.

(c) Theoretical studies of electron energy distribution in molecular gases.

(d) Studies of electron densities as a function of time in the afterglow of a microwave discharge in He.

Projected:

(a) Extension of studies in (a), above, to lower energies. Techniques to include mass analysis.

(b) Further development of 'trapped electron' method for measuring inelastic scattering cross section on N_2.

(c) Mass analysis of ions present in a microwave afterglow in (d) above. Also extension of the technique to O_2.

YALE UNIVERSITY - Dr. H. Margenau

In progress:

Theoretical study of the conductivity of ionized air in the microwave bands based on experimental values for collision cross sections.

Projected:

Extension of these studies to regions of the atmosphere excited by various radiations.

FOREIGN WORKERS

1. Adelaide, University of; R. W. Crompton, D. J. Sutton, L. G. H. Huxley - Experimental studies of low energy electron swarms.

2. Birmingham, University of; J. Sayers - Experimental studies of ionized gases.

3. British Columbia, University of, Vancouver, B. C.; C. A. McDowell - Experimental studies of low energy electron impact phenomena.

4. Laboratory for Mass Spectrometry, Amsterdam; J. Kistemaker - Experimental studies of charge exchange processes at kilovolt energies.

5. Leningrad State University; G. F. Drukerev - Theoretical studies of collision processes.

6. Liverpool, University of; J. D. Craggs - Experimental studies of negative ion formation and ionization in complex gases.

7. London, University of, Queen Mary College; B. A. Tozer

8. London, University College; R. L. F. Boyd, J. B. Hasted, H. S. W. Massey, M. J. Seaton - Experimental and theoretical studies of collision processes.

9. École Normale Superieux, Paris; J. E. Blamont - Charge exchange measurements.

10. Physical Technical Institute, Leningrad; V. M. Dukelsky, N. V. Fedorenko, F. M. Fogel - Experimental studies of negative ion formation and charge exchange.

11. Queen's University, Belfast; D. R. Bates, A. Dalgarno, V. L. Moiseiwitsch - Theoretical studies of collision processes.

12. Tokyo, University of, Tokyo; T. Yamanouchi - Theoretical studies of collision processes.

13. Wales; F. L. Jones - Electrical breakdown in gases.

14. Western Ontario, University of; P. A. Fraser - Theoretical studies of collision processes.

III. THE STATUS OF RESEARCH IN GASEOUS ELECTRONICS

The number of scientists working in the field of Gaseous Electronics has increased markedly in the past few years. One indication of this increase is the fact that twice as many papers were presented at the American Physical Society Gaseous Electronics Conference in 1958 as in 1951. Most of the increased research, however, has been in magneto-hydrodynamics and high energy plasmas. These fields are not particularly relevant to the problem that concerns Project QUICK KEY.

A relatively few laboratories with relatively small budgets are carrying on basic studies of low energy collision processes that are directly relevant to the ionosphere. A larger number of laboratories are carrying on experimental and theoretical studies of collision processes in other gases and at somewhat higher energies. Although many of these latter studies may not be directly relevant, they contribute basic understanding of processes and sometimes evolve important new techniques.

Even after fifty years of research there are still large gaps in our knowledge of some of the most fundamental and important processes. For example, there is a notable lack of charge-exchange data.

Because of the difficulty of interpreting experimental data, researches in this general area frequently seem to produce contradictory results. The discrepancy in various recently published values of the electron attachment rate to oxygen is an example. Duplication of measurements is desirable to resolve contradictions and establish confidence in data.

Theoretical studies of collision processes are limited by complexity largely to those involving hydrogen. Even with this gas, accurate calculations are possible for only the simplest collisions. Thus the earliest and most important data can be expected from experimental studies, although theoretical work should continue to be encouraged and supported.

Specific phenomena important for the understanding of electromagnetic wave propagation in the ionosphere after a nuclear explosion, and for which information is lacking, are listed below:

(a) Electron and ion differential and total scattering cross sections with atmospheric gases for energies up to 1 mev, but with particular emphasis upon the thermal energy range. Included here are the cross sections for excitation to various states including ionization and the velocity distribution of secondary electrons produced.

(b) Electron attachment rates and cross sections in air, O_2, O_3, NO, and NO_2 at low pressures and especially at low energies.

(c) Recombination cross sections of electrons with O_2^+, N_2^+, N^+, O^+, and NO^+.

(d) Radiative attachment to atomic oxygen.

(e) Photodissociation and photodetachment cross sections.

(f) Charge exchange cross sections (including ion exchange at low energies).

(g) Low-field electron mobilities in nitrogen and oxygen.

(h) Thermalization rates of electrons produced by gammas and X-rays.

(i) Electron collision frequencies.

Some of the items listed above are basic interactions involving two or perhaps three colliding particles. From measurements of these it is possible in principle to deduce values for others, involving averages over a wide energy range. Measurements of the averaged quantities also can be made.

Both kinds of measurement, individual and averaged, are valuable, so that computed averages can be compared with experiment and used to test our understanding of the complex of interactions.

Because it is not possible to predict either future needs for information or the fruits of research it is our feeling that research in gaseous electronics should be supported on a broad front rather than just for specific answers to current problems.

IV. APPENDIX

This section contains more detailed descriptions of research work than appeared in Section II.

Most of this information was obtained by visits to the laboratories and talks with the investigators. A large portion of the text is from letters and manuscripts solicited for this report from the researchers themselves. The inconsistent style of this section is due to our desire to make as few as possible editorial changes in the texts we received.

AIR FORCE CAMBRIDGE RESEARCH CENTER

At the Air Force Cambridge Research Center work is proceeding under the direction of Dr. O. Oldenberg on excitation of N_2 by protons in the energy range of 5-40 ev. This work extends in energy that done earlier by Dr. N. P. Carleton at Harvard. Ionization of N_2 by protons is also being studied. Further work will probably include study of collisions of fast neutral H atoms with N_2. The apparatus in use is capable of producing mass-resolved beams of any particular ion, and hence can be used to study collisions between many other pairs of particles beside protons and N_2 molecules.

UNIVERSITY OF ARKANSAS

Dr. Fan states that recently they received some support from AFCRC for work on atomic excitation with the 400-kv Cockcroft-Walton accelerator at the University of Arkansas. He will bombard the gases with protons from the accelerator and observe the optical spectra. He is interested in studying the basic atomic impact processes in O_2 and N_2.

Most recent experimental work published as "Emission Spectra Excited by Electronic and Ionic Impact," Phys. Rev. 103, 1740 (September 15, 1956). More recent theoretical work relates to charge exchange collisions.

His collaborator, Dr. Raymond Hughes, is interested in studying the polarization of atomic lines by electron impact.

AVCO RESEARCH LABORATORY, EVERETT, MASSACHUSETTS

For the past three years. the AVCO Research Laboratory, which is under the direction of Dr. Arthur R. Kantrowitz and located at Everett, Mass., has engaged in extensive studies of many chemical physics problems associated with the re-entry of ballistic missiles and Earth satellites. The earlier phase of this work involved the determination of the spectral emissivity and the electromagnetic properties of high temperature air under conditions of quasi-thermal equilibrium, while more recent phases of this work include the determination of the important chemical kinetic paths and related rate constant (inelastic cross sections) which govern the rates of dissociation, ionization and photo excitation behind strong shock waves, as well as the atom-atom and electron-ion recombination rates in an expanding flow field of high temperature air and other gases of interest.

In these studies, the high temperature shock tube has been the principal experimental tool. The unique advantage with which the shock tube adapts itself to this type of study is that it allows one to generate relatively uniform and reproducible gas samples over a wide range of temperature and density in a form which is readily suitable for many types of quantitative measurements. For example, the low energy electron scattering cross section of atomic oxygen has been successfully measured through observation of the microwave transmission and reflection characteristics of shock-dissociated oxygen, and it is believed that the cross sections of atomic nitrogen and many other chemically active species can likewise be determined.

A representative list of papers and reports already published (or to appear in the open literature shortly) on related topics is shown on the following page.

LIST OF PUBLICATIONS

1. Keck, J. C., Kivel, B., and Wentink, T., "Emissivity of High Temperature Air," AVCO Research Report No. 8, April 1957, HTFM Inst., Preprints of Papers, Stanford University Press, 1957, ASTIA AD 150 789.

2. Kivel, B., and Bailey, K., "Tables of Radiation from High Temperature Air," AVCO Research Report 21, December 1957.

3. Kivel, B., Mayer, H., and Bethe, H., "Radiation from Hot Air, Part I--Theory of Nitric Oxide Absorption," Annals of Physics, Vol. 2, July 1957.

4. Wentink, T., Jr., Planet, W., Hammerling, P., and Kivel, B., "Infrared Continuum Radiation from High Temperature Air," J. Appl. Phys., Vol. 29, April 1958.

5. Keck, J., Camm, J., and Kivel, B., "Absolute Emission Intensity of Schumann-Runge Radiation from Shock Heated Oxygen," J. Chem. Phys., Vol. 28, April 1958.

6. Lamb, L., and Lin, S. C., "Electrical Conductivity of Thermally Ionized Air Produced in a Shock Tube," AVCO Research Report 5, February 1957, J. Appl. Phys., Vol. 28, July 1957, ASTIA AD 150 549.

7. Hammerling, P., Shine, W. W., and Kivel, B., "Low Energy Elastic Scattering of Electrons by Oxygen and Nitrogen," AVCO Research Report 6, March 1957, J. Appl. Phys., Vol. 28, July 1957, ASTIA AD 150 621.

8. Camac, M., and Petty, C. C., "Oxygen Vibration and Dissociation Relaxation Rates in Argon and Oxygen Mixtures," AVCO Research Report 25, IAS Preprint 802.

9. Keck, J. C., "A Statistical Theory of Chemical Reaction Rates," AVCO Research Report 20, May 1958, J. Chem. Phys., Vol. 29, August 1958.

10. Wentink, T., Jr., Sullivan, J. O., and Wray, K., "Nitrogen Atomic Recombination at Room Temperature," J. Chem. Phys., Vol. 29, July 1958.

11. Lin, S. C., "Ionization Phenomena of Shock Waves in Oxygen-Nitrogen Mixtures, AVCO Research Report 33, June 1958, Presented at the 18th Conference on Physical Electronics, M.I.T., Proceedings of the Conference, 1958.

12. Feldman, S., "Chemical Kinetics of Air at High Temperatures: A Problem in Hypersonic Aerodynamics," AVCO Research Report 4, 1957, February 1957, HTFM Inst. Preprint of papers, Stanford University Press, 1957, ASTIA AD 150 548.

13. Davidson, Norman, "Selected Reactions Involving Nitrogen and Oxygen, AVCO Research Report 32, June 1958.

14. Lin, S. C., and Teare, J. D., "Shock Wave Structure in the Hypersonic Flight Regime," Presented at the A.P.S. Division of Fluid Dynamics Meeting at San Diego, California, November 24, 1958.

15. Hammerling, P., Teare, J. D., and Kivel, B., "Radiation from Nitrogen Shock Front," to be presented at the A.P.S. Annual Meeting at New York, N.Y., January 28-31, 1959.

16. Lin, S. C., and Kivel, B., "Slow Electron Scattering by Atomic Oxygen," to appear in <u>Physical Review Letters.</u>

CONVAIR, SAN DIEGO

Molecular Beam Research

Research Planned. Convair has a molecular beam tube in which beams of neutral particles having energies from a few hundredths to a few tenths of an ev will be employed. This tube will be used for measurements of the cross sections for scattering of electrons by atmospheric species, e.g., N_2, N, O_2 and O. Initially interaction energies will be varied between about 1 and 10 ev. Later it is hoped to do scattering experiments at energies less than 1 ev.

The first experiments are being done with atomic and molecular oxygen. While these experiments are being run, side experiments will be conducted for obtaining a source of atomic nitrogen with sufficient flux to permit a scattering experiment to be made.

It is planned to fabricate a second molecular beam tube for use with beams of neutral particles having energies in the range 1-15 ev. This energy range includes these interaction energies which occur between a hypersonic vehicle in the free molecule flow regime and atmospheric species in this regime. Experimental investigations are planned to study recombination, diffuse scattering and specular reflection, and accommodation and momentum transfer coefficients for atoms and molecules striking solid surfaces.

Research Done. A joint Convair-General Atomic experiment on the elastic scattering of electrons from hydrogen atoms and molecules was done by R. T. Brackmann, W. L. Fite, and R. H. Neynaber.* Satisfactory agreement with theory was found.

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*A paper covering this experiment entitled "Collisions of Electrons with Hydrogen Atoms--Part III--Elastic Scattering" has been submitted to *Phys. Rev.* for publication.

Work has also been done on developing atomic oxygen and nitrogen sources. A suitable source has been found for atomic oxygen, but not for atomic nitrogen.

Equipment. All equipment for the planned electron-atmospheric particle scattering experiments is on hand. This includes a beam tube, vacuum system and electronic and detection system.

The laboratory for the 1 kev molecular beam tube has not yet been set up.

UNIVERSITY OF FLORIDA, GAINESVILLE, FLORIDA

Scattering of Low Energy Negative Ions in Gases- T. L. Bailey and E. E. Muschlitz, Jr. (supported by ONR--Physics Branch)

These experiments are of the ionic beam type, in which a mass analysed beam of negative ions is sent through a collision region containing gas at low pressures ($\sim 10^{-3}$ mm Hg). Currents of elastically scattered ions, of slow negative particles produced along the scattering path, and of unscattered ions are measured separately. These measurements give cross-sections for elastic scattering, and the sum of cross sections for all processes which produce slow negative particles, as a function of ion energy. Thus far, the only inelastic cross section measured quantitively has been that of collisional electron detachment (e.g., H^- (fast) + He = H (fast) + e^- (slow) + He).

To date, elastic and electron detachment cross sections have been measured for the systems $H^- - H_2$, H^- - He, H^- - Ne, H^- - A, in the energy range 400 - ~4 e.v. Measurement of the elastic cross sections (over this approximate range in energy) for $H^- - O_2$, $O^- - O_2$, $O_2^- - O_2$, and $OH^- - O_2$ have been started. In the near future they will extend their measurements to the quantitative determination of electron exchange cross sections in the presence of electron detachment; this will be accomplished by means of a radio frequency electron filter incorporated in the collision chamber.

Elastic and Inelastic Scattering of Low Energy Positive Ions in Gases at Low Pressures--W. H. Cramer (supported by N. S. F. Grant)

Potential energy force fields between ions and molecules are being investigated by means of ion-scattering experiments. Both elastic and inelastic collision cross sections are determined in the energy range from a few electron volts to a few hundred electron volts. A beam of ions produced in a special mass spectrometer is introduced into a collision region containing a scattering gas at low pressure. From analysis of the scattering measurements parameters for potential functions may be determined.

Collisions of He^+, Ne^+, and A^+ in the gases He, Ne, and A have been investigated. Charge exchange was observed only in the symmetrical cases. The binding energy obtained for He_2^+ is in good agreement with values obtained by other means.

Present work involves study of hydrogen and deuterium ion scattering in H_2 and D_2. Elastic cross sections for deuterons in D_2 have been found to be similar to earlier measurements by Simons and co-workers for protons in H_2. Charge exchange was observed for deuterons in D_2 above 80 volts ion energy.

Among the problems under consideration for the future are formation and collision of beams of neutral particles in this same energy range with molecules and scattering of hydrogen ions and alkali ions in the inert gases.

Collisions of Metastable Atoms in Gases--E. E. Muschlitz, Jr. (supported by N. S. F. Grant)

Using molecular beam techniques, total collision cross sections have been measured for the scattering of thermal beams of 2^3S and 2^1S helium atoms in He, Ne, and A. The ionization cross sections have also been measured for these metastable atoms in argon. At the present time the resolution of the apparatus is being increased in order to detect the scattering at small angles.

Future work planned in this area includes modification of the apparatus to increase the precision of the results and the extension of the measurements to other metastable atoms, particularly Ne^* and A^*. Collisions of the type:

$$X^* + Y_2 \longrightarrow X + Y + Y$$

involving transfer of excitation energy will also be investigated. In addition, the apparatus is capable of measuring "free space" lifetimes of excited atoms and molecules in the range 10^{-2} to 10^{-6} second.

Negative Ion Formation; Ion-Molecule Reactions--E. E. Muschlitz, Jr., W. H. Cramer, T. L. Bailey (supported by N. S. F. grant)

A first order direction focusing. homogeneous magnetic field, sixty-degree radial magnetic deflection, twelve-inch radius of curvature mass spectrometer is now under construction in the Department of Chemistry at the University of Florida. Maximum resolution of the instrument will be about 1:1000. An electron multiplier will eventually be used to increase the sensitivity of the instrument. It is expected that construction will be completed by the fall of 1959. With the exception of the ion source and differential pumping system, the instrument is based on original designs of Professor M. G. Inghram of the University of Chicago.

It is planned to use the instrument initially for studies of negative ion formation by electron bombardment in gases at relatively high pressures, particularly O_2^-, OH^-, and hydrocarbon negative ions. Versatility in the construction of the instrument will enable several types of ion sources to be employed interchangeably. Future work envisioned with the instrument includes definitive studies of ion-molecule reactions in gases.

Personnel

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2. T. L. Bailey, Associate Professor of Electrical Engineering. Ph.D. (Physical Chemistry) University of Chicago.

3. W. H. Cramer, Assistant Professor of Electrical Engineering. Ph.D. (Physical Chemistry) Pennsylvania State University.

4. Consultant--J. H. Simons, Professor of Chemical Engineering and Chemistry. Ph.D. (Chemistry-Physics) University of California.

GENERAL ATOMIC

The Atomic Beam Laboratory at General Atomic in San Diego, under the direction of Wade Fite, is at present an instrument-centered laboratory, and the work there revolves about the use of modulated atomic beam techniques. The major application has been made to properties of hydrogen and oxygen atoms, although some work has been done on molecules of hydrogen, oxygen, and nitrogen. In the use of atomic beam techniques densities are very low and events studied are single-collision events. The intrinsic cleanliness of the atomic beam approach allows rather simple interpretations of experiments; for multiple collision processes, wall effects, and so forth do not enter those experiments dealing with atomic collision phenomena. The types of properties which have been measured include: ionization on electron impact of atoms and molecules, excitation to discrete states, elastic scattering, and charge exchange between ions and neutral species.

Plans for future call for experiments on collisions where metastable atoms are involved, interactions between positive ions and negative ions or electrons, ionization on ion impact, and charge exchange and stripping in collisions between negative ions and atoms.

Attempts, unsuccessful to date, have been made to measure radiative attachment cross sections for the formation of negative ions.

The cross section as a function of electron energy for the reaction

$$e^- + O \rightarrow O^+ + 2e^-$$

was measured for electron energies up to 500 ev. The results of this experiment along with comparisons made to a theoretical curve calculated by M. J. Seaton will appear in a forthcoming issue of Physical Review Letters.

Details of the experimental techniques employed are given in two General Atomic Reports, GA-339, "Collisions of Electrons with Hydrogen Atoms" by Wade L. Fite, R. T. Brackmann, and Roy H. Neynaber, and GA-407, "Charge Exchange in Proton-Hydrogen-Atom Collisions" by Wade L. Fite, R. T. Brackmann, and W. R. Snow. Both of these reports will appear soon in the Physical Review.

Some specific experiments the group is interested in performing in the future are listed below. The first group involves collisions of ions and atoms.

1. $O^{\pm} + O \rightarrow O + O^{\pm}$. These charge exchange cross sections are measurable with the method for GA-407, and absolute values can be obtained from comparison with the $p + O_2$ and $e + O$ ionization cross sections.

2. $p + O \leftrightarrows O^{+} + H$. This process is important in the excitation of aurora and penetration of protons from the sun into the earth's atmosphere. It can be measured as described in GA-407.

3. $p + O \rightarrow p + O^{+} + e$.

As explained in GA-407, the earliest attempts to measure the ionization by protons on hydrogen were not successful because of high noise level. Improvements in apparatus make it appear possible now to do that experiment, and the above cross section as well. Absolute values will come from comparison with charge-exchange cross sections.

4. $O^{-} + O \rightarrow \left\{ \begin{array}{c} O + O + e \\ O_2 + e \end{array} \right\}$.

Liberated electrons will be detected. Energy analysis of liberated electrons may identify neutral end products. The liberation of electrons accompanying the formation of a molecule is believed to be responsible for maintenance of electron layers at night in the ionosphere, and the cross section is the most poorly known of the cross sections pertinent to ionospheric theory.

The second group of proposed experiments would measure the elastic and inelastic scattering from groundstate atoms of hydrogen and oxygen. In these experiments, the electrons scattered by oxygen and hydrogen atoms will be detected with the basic technique described in GA-339, Part III. The detector, of finer angular resolution than used previously, will be movable so that angular distributions can be obtained, and it will be preceded by a velocity analyzer so that the energy distribution of the scattered electrons will be measured. The result of this experiment with oxygen atoms is the information required for the problem of electric drag on satellites.

The scattering of electrons by groundstate atomic hydrogen is the most fundamental single problem in the theory of scattering and the results of this experiment with hydrogen atoms would be of importance to every application of scattering theory. Ratios of cross sections of the atom and the molecule are directly measurable, and the molecular cross sections are sufficiently well known to allow calibration of relative cross sections.

Also at General Atomic an experiment has been set up by Dr. Victor Van Lint and is in progress to measure electron recombination and attachment rates. Ionization is produced by a short burst of electrons from the General Atomic 32 Mev. electron linear accelerator. The instantaneous electron density in the ionized gas is observed using standard microwave techniques.

The electron linear accelerator is capable of producing pulses of ionization from 0.2 microsecond to 5 microseconds in duration. The instantaneous flux of electrons during this pulse is adjustable up to a maximum in excess of 10^{17} electrons/mm^2-sec. In a gas at atmospheric pressure this radiation will create electron ion pairs at a rate as high as 10^{19} pairs/cm^3-sec. The rise and fall times on the accelerator pulse can be adjusted to be as short as 0.1 microsecond.

The measurements in progress at present utilize 3 cm (X-band) microwaves in a waveguide. The microwave circuit consists of a reflex-klystron oscillator feeding equally into two arms of a magic hybrid ring. A measured length of one of the arms is then irradiated with the accelerator electron beam and the transient imbalance in the transmitted amplitude and phase and the reflected amplitude are observed. The sensitivity of the system is such that electron densities as low as 10^9 electrons/cm^3 can be measured conveniently. If it becomes necessary to perform experiments on lower electron densities than this value, it will be a fairly straightforward matter to exchange the magic hybrid ring for a cavity which can be irradiated.

It is expected that the major uncertainty in this experiment is the effect of the diffusion of electrons to the wall of the waveguide. Since the entire experiment is finished in a matter of a microsecond or so, this diffusion effect is certainly negligible at pressures near atmospheric pressures. It is believed that the effect is also negligible down to pressures as low as 1 mm Hg as long as measurements are not performed over a long period of time following the irradiation. There are plans for proving this point by replacing one arm of the magic hybrid ring by a pair of microwave horns and irradiating the gas in between the horns. In this experiment diffusion will certainly be negligible.

It is also believed that utilizing high-energy ionizing radiation is a clean method of producing the ionization. A relativistic electron passing through a gas is extremely efficient at removing electrons from atoms and molecules but is very inefficient for exciting molecules in any other way. The problems which have plagued experiments performed in the after-glow of gas discharges and which can be attributed to molecular excitations should not be present in these experiments.

GENERAL ELECTRIC COMPANY, MISSILE AND ORDNANCE SYSTEMS DEPARTMENT

Dr. Breene states that his main interest is radiation, and his interest in free electrons, atoms and molecules is from this point of view. This, of course, implies matrix elements and this in turn implies wave functions, which is the prime consideration. Scattering will enter since after all we must find a phase shift in obtaining an asymptotic solution for our free electrons; but scattering only enters into his considerations indirectly. He has general IBM 704 programs for the determination of emissivities from gaseous or plasma layers. Into these programs as input he needs for the various continuum radiation, matrix elements for free-free and free-bound continua. Other types are also needed but these should be of no interest to the scattering problem.

In the past, various very approximate solutions for the Schroedinger equations for free electrons in the presence of various atoms have been utilized. The one exception is the simple hydrogen case which was developed by Chandrasekhar. The Born approximation is admittedly good for the higher order waves and for the high velocities, but at velocities of interest in continuum radiation this is anything but the case for the S-wave. Therefore, he has developed potentials from atomic wave functions for these electrons in the presence of atoms. He has developed a treatment for exchange which is now working on the IBM 704. The polarization treatment is underway, but is much more complex and will be some time in completion. For free electron wave functions without either exchange or polarization the IBM 704 programs are written and have been described.(1) In order to obtain the potential with or without exchange one needs atomic wave functions. He has written two programs for the IBM 704 for the determination of wave functions for atoms having electrons through 3p.[2,3] The large variation calculation for atomic wave functions is due to appear in the very near future in the Physical Review, but it has already been put out as a research memorandum.[3]

The situation is as outlined in his C^- paper; he determines the wave function for the atom under whose aegis the free electrons exist. From this wave function he determines a Coulomb potential for the free electron. This potential is utilized on an IBM 704 program to determine the free electron wave function. A self-consistent field treatment presently programmed on the IBM 704 can then be utilized to determine the free electron wave function with exchange. This, in turn, can be subjected to the rather extensive perturbation treatment needed to obtain the free electron wave function with polarization of the atomic charge cloud. For the bound-free or de-ionization continua he then utilizes these wave functions in existent IBM 704 programs in order to compute the matrix elements. He is in the process of writing an IBM 704 program for the computation of the matrix elements for free-free transitions.

Speculatively, he hopes to extend his treatments to wave functions for electrons in the fields of diatomic molecules. Along this line he currently has an IBM 704 computation for molecular orbitals. The realization of this program is somewhat in the future.

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GEORGIA INSTITUTE OF TECHNOLOGY

At Georgia Institute of Technology gaseous electronics research is being done under Professor Earl McDaniel. Work in the field of ion mobilities has consisted of measuring the low field mobilities of negative ions in oxygen and mixtures of oxygen with non-electronegative gases and pure SF_6, HCl and SO_2. A lengthy report on this work exists and a paper has been submitted to the Physical Review which also gives some theoretical results obtained by some English researchers.

Current work is directed toward studying reactions that occur between thermal ions and gas molecules. Ions are produced at the end of a 10-ft long drift tube and allowed to drift the length of the tube in an electric field of about 1 volt/cm at pressure of about 1 mm of mercury. The ions are extracted from a stream of gas issuing from a pinhole at the end of the tube and analysed in a mass spectrometer.

Positive ions will be used initially (He^+, Ne^+, A^+, H^+, and O^+_2). Later negative ions will be used.

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HARVARD UNIVERSITY

At Harvard the excitation of nitrogen by protons of a few kev energy has been investigated by Dr. N. P. Carleton, to aid in interpreting auroral spectra. The dependence of the intensity of the various spectral features on the proton current and gas pressure gives evidence about the excitation mechanism (see N. P. Carleton, Phys. Rev., 107, 110, July 1, 1957). Cross sections for excitation by proton impact have been measured. Interference filters select various spectral features and a photomultiplier detects the light emitted. Also included are measurements of the total charge-exchange cross section for protons in nitrogen and an estimate of the ionization cross section (see N. P. Carleton and T. R. Lawrence, Phys. Rev., 109, 1159, February 15, 1958).

Experiments may be continued at Harvard in the low energy range, 0.1-5 kev, on excitation resulting from collisions of heavy atoms and ions, such as are evaporated from meteors, with oxygen and nitrogen.

HUGHES AIRCRAFT COMPANY

A group under Dr. Elsa Huber Solt has been active in the field of high frequency (10 mc to 9000 mc) electrical breakdown in gases. Measurements of breakdown fields as a function of pressure, geometry, and frequency are being made on O_2, N_2, He, Ne, A, and air. Measurements of the rate of electron density decay have been made which give information on the electron attachment rates for attaching gases.

They have also done work on the propagation of microwaves through ionized gases. Their current interest in this field is in measuring the Faraday effect and attenuation and reflection caused by densities above the density of total reflection for an infinite medium. They are adopting their experimental techniques for plasma diagnostics.

UNIVERSITY OF ILLINOIS

Professor L. Goldstein gives the following account of his work at the University of Illinois.

Past work was on interaction processes that take place in plasmas in the noble gases and in nitrogen and oxygen.

They are making measurements on the electron collision cross section of nitrogen molecules from room temperature down to $77^{\circ}K$, in which the electrons are in thermal equilibrium with the gas. Also, they are measuring the electron collision cross section with oxygen.

They have done and will repeat measurements of electron attachment cross section in oxygen and possibly ozone. The electrons will be essentially at thermal equilibrium with the gas, and the temperature will be lowered to $77^{\circ}K$.

These processes are studied by microwave probing plasmas in two types of experiments. Microwaves are propagated in the plasmas at low levels, and the electron density and collision frequency as a function of time are computed from attenuation and phase shift measurements.

Two frequencies are propagated through the plasma, making it possible to deduce characteristic quantities regarding the plasma processes with electrons from the interaction of the microwaves with the plasma. That is, the effect of one frequency on the plasma is measured by a probing frequency. All of the measurements are correlated with optical measurements.

They have plans for making a mass analysis of the ions present by obtaining cyclotron resonance on the ions. This will be difficult because it will have to be done at temperatures and pressures where the collision frequency of the ions is not too high compared to cyclotron frequency of the ions.

Among the plasma interaction processes that they have been investigating is the electron-electron interaction.

Professor Goldstein is also considering the effects that might be produced by heating the electron gas in the ionosphere. Because of the power requirements it will probably be easier to do this from a flying vehicle than from the ground. He would heat up the electron gas by pumping in power at the cyclotron frequency. The heating will vary the charge density because the rate of disappearance of electrons by attachment or recombination will be changed. This should be a rather sizable effect for a reasonable power expenditure in the E layer if the heating power is introduced at the cyclotron frequency in the earth's field, about 1.3 mc.

His work is supported by the Air Force Cambridge Research Center. The ionospheric work is supported by the Geophysics Research Directorate under contract AF3481, and the Gaseous Electronics work is supported by the Electronic Directorate under contract AF 19(604)-2152.

LOCKHEED MISSILE SYSTEMS DIVISION

Atomic and Molecular Reaction Studies at Lockheed

A general program investigating charge exchange and ion-atom interchange reactions is presently underway in the Space Physics Department. Emphasis is being placed on those reactions whose cross sections would be large at the lowest kinetic energies achievable in the apparatus. It is felt that these reactions would be particularly significant in determining the composition balance of both neutral and ionized species in the ionosphere.

A crossed beam reaction system is being used to study the reaction

(1) $O^+ + N_2 \rightarrow NO^+ + N, \ \Delta E = 1.1$ ev.

An N_2 beam is being crossed with a low energy O^+ beam, which has previously been mass selected in a conventional low resolution magnetic analyser. The charged reaction product NO^+ is to be detected with a strong-focusing mass filter of the kind developed by W. Paul. Use of O_{18}, and an O_2 beam will allow the reaction

(2) $O^+ + O_2 \dashrightarrow O_2^+ + O, \ \Delta E = 1.4$ ev,

to be studied. Use of O_{18} will discriminate between ion-atom interchange and the charge exchange, the former giving $O_{18}\,O_{16}^+$ as the product, the latter $O_{16}\,O_{16}^+$. In addition, the reverse of the reaction

(3) $O_2^+ + N \rightarrow NO + O^+, \ \Delta E = 0.0$ ev,

may be investigated, using NO in the neutral beam. From a knowledge of the equilibrium constant the forward rate may be inferred. Present plans call for the measurement of these cross sections and their energy dependence down to the lowest energies obtainable (less than 10 volts).

Future plans are being made for the study of two reactions which are of particular practical, as well as theoretical, interest.

(4) $H^+ + O \longrightarrow O^+ + H$, $\Delta E = .02$ ev,

and (5) $H_2^+ + H \longrightarrow H_2 + H^+$ (ion-atom interchange), $\Delta E = 1.8$ ev.

A strong focusing mass filter in the range 1 to 4 AMU, which has been developed in their laboratory, may be used in generating the low energy protons. It would also be used as a detector for (5). The atomic oxygen required for (4) would be obtained in a radio-frequency gas discharge. Reaction (4) should exhibit a very strong resonance effect since its energy defect is nearly zero. As a result, it should have a very large cross section at low energies. Reaction (5) is the simplest conceivable ion-atom interchange reaction.

Electromagnetic Propagation Studies

The fundamental quantities affecting electromagnetic propagation are being studied.

NATIONAL BUREAU OF STANDARDS

Following is a summary of that part of the program of the Atomic Physics Section of the National Bureau of Standards which relates to determination of atomic cross sections at low energies.

1. The group working on measurement of interactions in ion beams has consisted of Drs. L. M. Branscomb, D. S. Burch, and S. J. Smith. Burch has recently left for an academic job. This group is supported by an instrument maker and two laboratory assistants plus the large shop and other facilities of NBS.

The major effort has been expended on photodetachment of electrons from negative ions. Cross sections have been measured for photodetachment from O^-, O_2^-, OH^-, and H^- in the spectral range from 4000 A to 2.4 μ. Thresholds have been determined with great accuracy for detachment from O^- and OH^-, and with less accuracy for S^-. The photodetachment program on the present apparatus is essentially completed. They feel that their program could be extended in several very interesting directions with a large aperture monochromator of special design. Measurements could be extended into the ultraviolet region of the spectrum, and, also, the continuous scanning and optimum resolution available in such an instrument would allow them to study structure in photodetachment cross sections, particularly for molecular negative ions. At present there are no funds for such an instrument.

A measurement of the cross section for inelastic scattering of electrons by negative ions, in a crossed beam arrangement, is also underway in an effort to follow up a calculation of this cross section by Geltman (see below).

In addition to this work in progress several measurements of interest to astrophysics and fusion research have been designed, including measurements of electronic excitation of several astrophysically important spectral lines.

2. Dr. Sydney Geltman has been engaged in a program of calculation of low-energy collision cross sections using the 704 computer at NBS. He has essentially completed a calculation of the elctron-H^- detachment cross section, yielding unexpectedly large values at low electron energies. He has in progress a calculation of elastic scattering of electrons from hydrogen atoms. In addition he has recently developed a theory of shapes of photodetachment cross sections near threshold, and is working on mobilities of positive ions at low temperatures.

3. Dr. Earl Beaty is in the process of refining an apparatus for measurement of mobilities of positive ions in gases using recent high vacuum and electronic techniques.

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NAVAL RESEARCH LABORATORY

Equipment to make measurements of the absorption and reflection of microwaves from highly ionized air at low pressures is under construction. These measurements will lead to a better understanding of attachment and recombination processes in highly ionized air.

The measurements will be carried out in a tank, 54 inches in diameter and eight feet long, maintained at pressures of 10 mm or lower. Air along the axis of the tank will be ionized by a 10 amp, 1 microsecond pulse of 100 Kev electrons entering the tank through a differential pumping system. A pair of microwave horns with dielectric lenses mounted on opposite sides of the tank will be used in the absorption and transmission measurements.

An electron gun will produce a 10 amp, sheet-shaped beam of 100 Kev electrons with 1 cm x 10 cm cross section as the beam enters the tank. This electron beam with current density of 1 amp/cm^2 for 1 microsecond will produce the order of 10^{13} ion pairs per cm^3 in air at 1 mm pressure.

The initial measurements will be performed with X-band radiation.

NEW YORK UNIVERSITY, INSTITUTE OF MATHEMATICAL SCIENCES

The kind of work that Professor Borowitz is doing relates to finding some approximate theoretical methods for dealing with electron scattering processes, both elastic and inelastic, which are of some importance in the field of gaseous discharge. He has been applying his results to the hydrogen atom as a sort of laboratory to test them. In this connection he has examined the elastic and inelastic scattering of electrons by hydrogen atoms using variational methods, perturbation methods and the impulse approximation.

Another type of activity which is related to the one described is finding approximate wave functions to characterize systems of many particles in an atom. As examples of this type of activity, he is working on a method for finding the charge distribution for excited states of atoms in a Thomas Fermi approximation and is looking for product wave functions involving the interelectronic coordinates for heavier atomic systems.

A third type of activity is the investigation of scattering processes by novel methods. As an example of this, he has developed a perturbation procedure which can be used to calculate the scattering of two molecules by each other assuming that the potential between them is represented by a hard sphere at small distances and a weak attractive potential at larger distances.

University Heights Campus

Professor Benjamin Bederson and his graduate students have an extensive program underway to measure differential elastic scattering cross sections of the electrons from atoms. At present they apply this technique only to alkali atoms. Their technique for measuring differential elastic scattering cross sections of electrons from atoms has some interesting characteristics worthy of description. Direct measurements of the angular deflection caused by low energy electrons in collisions with atoms are difficult to obtain because very small stray electric fields can give rise to additional deflections, making angular resolution difficult to obtain. Bederson's method of measuring the angular deflection of the electrons is to measure instead the deflection of the deflecting atom, which is much less, but can be measured much more precisely. A collimated beam of atoms from a furnace is passed first through an inhomogeneous magnetic field, splitting the beam of atoms into beams of atoms having different states of electron angular momentum. The scattering is then done off one of these beams. The measured deflections of the beams are then converted back to the electron frame of reference to determine the differential scattering cross section for the electron. Further plans call for an additional region of inhomogeneous magnetic field after the collision region to determine any change of angular momentum taking place during the collision.

Professor Bederson is considering doing the following particular problems, which are of importance to work on the ionosphere.

1. Elastic scattering of atomic oxygen by slow electrons.
2. Inelastic scattering of atomic and molecular oxygen and molecular nitrogen by electrons.
3. Ionization cross sections for atomic oxygen.
4. The production of atomic nitrogen in beams.

PROVIDENCE COLLEGE

Professor Fineman states that the overall purpose of his work is to learn more about the nature of negative ions which are formed by electron bombardment of various molecules. Important quantities such as electron affinities of atoms, radicals and molecules may be determined as well as cross sections for electron attachment (with and without dissociation). In addition to these properties of negative ions or negative ion formation, one can also measure bond dissociation energies of molecules and radicals and ionization potentials of molecules, radicals and atoms.

He has constructed a Lozier apparatus to make such studies. A Fox gun is used in this instrument in order to use an essentially monoenergetic electron beam for bombardment. One of the main advantages of this instrument, not considering its inexpensiveness, is that the kinetic energy with which fragment ions are formed can be measured.

He has reinvestigated N_2 and CO. In the case of CO, he has determined the electron affinity of carbon as being 1.33 ev, which is in good agreement with the only other experimental determination of this quantity.

His immediate plans are to clear up several disturbing problems with respect to some of the very important diatomic molecules N_2, CO, O_2, and NO, and to determine the electron affinity of carbon using some other molecules than CO. Once these investigations have been completed, he intends to investigate systematically homologous sets of compounds such as alcohols, ethers, amines, etc.

OHIO STATE UNIVERSITY

The results of the research at Ohio State under Professor Lassettre may be summarized as follows:

1. Collision cross sections for N_2, O_2, CO_2, H_2O have been determined throughout the excitation spectrum from 0 to 80 volts excitation energy as functions of angle. Less extensive studies of other substances have been conducted as indicated in the list of reports below.

2. Total collision cross sections for oxygen have been calculated from the data by integrating over angle, and it has been found that approximately 10 per cent of the inelastic collisions between 500 ev electrons and oxygen molecules lead to excitation to the dissociation continuum of the Schumann-Runge band system and, hence, to dissociation into atoms. Similar calculations have been made for one transition in H_2O.

3. Oscillator strengths have been calculated by extrapolation from the measured electronic collision cross sections of atmospheric gases. These can be compared with determinations, by other investigators, using methods based on radiation absorption. Such comparisons have been made in several instances, and the oscillator strengths determined by electron impact methods usually agree somewhat better with optical determinations which employ photographic detection methods than with those which employ photoelectric methods in the measurement of radiation intensities. Since the electron impact method is new and the theory which relates oscillator strength to collision cross section is approximate (the Born approximation), even the worst discrepancies encountered are probably not excessive. This is especially true since the methods are radically different. The final position on this matter is summarized in Scientific Report No. 12.

4. The technique for the determination of collision cross sections has been tested by measurements on helium. The theoretical collision cross section for the 1'S 2'P transition in helium agrees very well with that determined experimentally, at least as far as curve shape is concerned. Moreover, oscillator strengths determined experimentally from the ionization limit (24.6 ev) to excitation energies of 48 ev agree quite well with theory (see Report No. 9). At higher excitation energies, the double excitations, which involve the simultaneous excitation of two electrons, are encountered. In this region, no accurate theory exists with which the experimental results can be compared. Moreover, when the continuum at one side of a peak is extrapolated it does not join smoothly to the continuum on the other side but instead is 20 per cent higher. Further and more elaborate theoretical work is required to account for these results.

Completed investigations of electronic collision cross sections, sponsored in part by the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command under Contract No. AF 19(122)-642, have been described in the following scientific reports:

Scientific Report No. 1. The Determination and Interpretation of Electronic Collision Cross Sections, by Edwin N. Lassettre.

Scientific Report No. 2. An Electron Spectrometer for the Study of Inelastic Collision Cross Sections, by E. N. Lassettre, A. S. Berman, S. Silverman and M. E. Krasnow.

Scientific Report No. 3. The Inelastic Scattering of Electrons by Helium, by E. N. Lassettre, M. E. Krasnow and S. Silverman.

Scientific Report No. 4. Inelastic Collision Cross Sections of Carbon Monoxide, by E. N. Lassettre and S. Silverman.

Scientific Report No. 5. An Electron Impact Study of Nitrogen in the Kinetic Energy Range 400 to 600 ev, by E. N. Lassettre and M. E. Krasnow.

Scientific Report No. 6. Electronic Collision Cross Sections and Oscillator Strengths for Oxygen in the Schumann-Runge Region, by E. N. Lassettre, S. Silverman and M. E. Krasnow.

Scientific Report No. 7. Electronic Collision Cross Sections for Oxygen at Excitation Energies above 10 Volts, by S. Silverman and E. N. Lassettre.

Scientific Report No. 8. Electronic Collision Cross Sections for Nitrogen at Excitation Energies from 10 to 80 Electron Volts, by S. Silverman and E. N. Lassettre.

Scientific Report No. 9. Additional Collision Cross Sections for Helium, Especially in the Ionized Continuum, by S. Silverman and E. N. Lassettre.

Scientific Report No. 10. A Collision Cross Section Study of CO_2, by Jerome Shiloff and E. N. Lassettre.

Scientific Report No. 11. Further Developments in the Theory and Use of the Electron Spectrometer, by E. N. Lassettre, S. Silverman, and M. E. Krasnow.

Scientific Report No. 12. Electronic Collision Cross Sections of Water Vapor, by E. N. Lassettre and E. R. White.

UNIVERSITY OF OKLAHOMA

The experimental work under Dr. Fowler falls into two classes. The first class is studies of atomic properties. They are studying the lifetimes of excited states directly by electronic methods. They are also studying cross-sections of atoms for electron impact at energies ranging from the excitation potential up to about 100 times the excitation potential. They are getting interesting results but have no publications yet. Their technique is to count the photons emmitted from the excited atoms. They work at pressures of less than a micron.

Their second class of experiments, supported by ONR, is a study of the plasma in a shock generated by a low pressure spark discharge. They study the shock during its expansion stage. Their work is aimed in the direction of determining as much as they can about the equation of state of the plasma.

Dr. Theimer is doing theoretical work on the conductivity of a plasma and on the theory of the microfield in a plasma. He got into this field in an attempt to explain anomalies they found in Stark broadening in gas discharges. He found that this work carried over very nicely to corrections to Spitzer's conductivity theory. He plans to publish a paper describing his theory of conductivity. Recent measurements by Turner at Ramo-Wooldridge confirm his theory quite well.

They intend to pursue this line of development of determining electron cross sections for quite a while. Their technique is quite good and can still be improved a good deal. They have a very sensitive low background photon counter--a 14-stage photomultiplier. They wish to go out into the ultraviolet for greater sensitivity but this will require more funds than are available.

UNIVERSITY OF PITTSBURGH

At the University of Pittsburgh a program of charge exchange cross section measurements has been under way for more than a year. One series of measurements which has already produced results aims to provide much more precise values for charge transfer cross sections than are now available. With the apparatus used, particles up to 70 kev are available. The scattering chamber consists of a beam preparation chamber in which the ion beam may be converted to a neutral beam if necessary, a series of nine identical condensers and a detector composed of a foil thermocouple inside a Faraday cup. In measurements of σ_{10} the gas ions produced by charge transfer are collected by the condensers operated at low voltage, and the currents to successively longer sequences of condensers are measured. σ_{10} for protons on H_2 by this method turns out to agree closely with the measurements of Stier and Barnett. The points obtained lie on a smooth curve with little scatter. The same apparatus may also be used to yield σ_{01}, σ_{0-1} and $\sigma_{10} + \sigma_{01}$. For $\sigma_{01} + \sigma_{0-1}$ high voltage is placed on the condensers and all ions are removed from the beam as soon as they are formed. The thermal detector, which can be calibrated with the help of the Faraday cup when the beam is purely ionic, responds to the total particle current. This current is given by

$$I_o \exp\left[- (\sigma_{01} + \sigma_{0-1})\, n\, m\, x_o\right] + \text{const.}$$

σ_{01} and σ_{0-1} are obtained separately from a measurement of the total current collected by each condenser. $(\sigma_{01} + \sigma_{10})$ is measured by applying high voltage to individual condensers rather than a bank of them.

σ_{01} and σ_{0-1} for hydrogen atoms measured in this way agrees fairly well with the Russian measurements and not at all with Stier and Barnett.

Plans are to use ions other than protons in this apparatus and gases other than H_2, D^+, He^+, He^{++}, N_2^+, N^+, O_2^+ in H_2, D_2, N_2 and air.

A beam apparatus of novel design is now being constructed primarily for the purpose of measuring σ_{10} for protons in atomic hydrogen. It will be possible to use it also for other charge transfer cross sections--in particular, as a check, for protons on molecular hydrogen. The experiment involves the formation of a beam of hydrogen atoms by charge exchange from a beam of 8 kev protons. With the help of a focusing magnet a beam of protons from a Cockcroft-Walten will be sent along with or counter to this beam. The protons formed in the 8 kev beam by charge transfer will be collected with the help of a magnet and a charged particle detector. Since protons of 8 kev would also be formed through electron loss in collisions between beam atoms and gas in the chamber, high vacuua are necessary. A differential pumping system of many stages employing ion pumps to obtain sufficiently high speed at low pressure will be used. This apparatus will soon be finished.

In the future it is hoped that charge exchange measurements may be carried out in collaboration with J. E. Blamont in Paris, using an atomic oxygen beam apparatus which he has devised.

UNIVERSITY OF SOUTHERN CALIFORNIA

Recent work at U.S.C. under Professor Weissler is summarized in the following technical reports and papers:

1. 'Photoionization Analysis by Mass Spectroscopy,' G. L. Weissler, G. R. Cook, M. Ogawa, and J. A. R. Samson, Bull. Amer. Phys. Soc., Ser. II, Vol. 3, June 1958, A, p. 259.

2. Technical Report No. 21 on the subject of (1) above, dated August 1, 1958, has been distributed.

3. A paper on subject (1) above was presented at the 11th Annual Conference on Gaseous Electronics, October 22, 1958 in New York.

4. Manuscript on subject (1) above has been accepted for publication by the Journal of the Optical Society of America, February 1959 issue.

5. 'Mass Analysis of Photoionization Products in Nitrogen and Nitrous Oxide,' J. A. R. Samson and G. R. Cook, contributed paper for APS-meetings, December 29-31, 1958, at UCLA.

6. 'Photoionization Induced Ion-Molecule Reactions in a Mass Spectrometer,' by G. R. Cook and J. A. R. Samson, contributed paper for APS-meetings, December 29-31, 1958, at UCLA.

7. 'Photon Absorption Mechanisms and Electrical Discharges Through Gases,' G. L. Weissler, invited paper for APS-meetings, December 29-31, 1958, at UCLA.

Particular attention is called to their work in which they combine a vacuum monochromator with a mass spectrograph (see (2) and (7) above). In addition, a new and very versatile grazing incidence (2.5 A/mm at 800 A) vacuum monochromator-spectrograph combination instrument is due for completion by about the end of 1958.

STANFORD RESEARCH INSTITUTE

At the Stanford Research Institute the Molecular Physics Section, which includes Drs. C. J. Cook. J. Peterson, O. Heinz, and Felix Smith, is concerned with electronic and atomic impact phenomena for impacting energies in the range from a fraction of an electron volt through many kilovolts.

Active projects with application to ionospheric problems are:

1. Research on Collision Processes of Electrons and Atoms, Office of Naval Research Contract Nonr-2588(00).

Apparatus is under construction to be used in determining the ionization cross section for O, N, O_2 and N_2 by slow electrons. A crossed beam experiment will be performed. Neutral beams of various species will be produced from intense ion beams by a charge exchange process. The ion beams will be produced by an accelerator recently developed at Stanford Research Institute by the Molecular Physics Section.

2. Impact of Ions and Electrons on Gases, Air Force Cambridge Research Center, Contract No. AF 19(604)-3475.

The experimental investigations briefly discussed above have led to novel apparatus and techniques, which in turn have led to the conception of new experiments that might now be possible by properly utilizing our available equipment. Feasibility studies are underway on two of these. It is hoped that one study will show that the differential scattering cross section for slow electrons by atoms and molecules can be determined for impacting energies ranging from a fraction of an ev to several hundred ev. A novel twin beam experiment is being considered that will, it is hoped, furnish sufficient data to accurately determine the rate coefficients or reaction cross sections for large classes of two-body reactions--ion-ion recombination would be a particular case. Calculations are underway to determine the feasibility of this experiment.

SYLVANIA ELECTRIC PRODUCTS CORPORATION

Present work at the Sylvania Microwave Physics Laboratory at Mountain View, California in upper atmosphere physics is being sponsored primarily by the Air Force Cambridge Research Center under Contract No. AF 19(604)-3883. This contract covers two distinct studies. The first of these is probably of less interest to ionospheric research. It is a study of the buildup of electron density in air under the influence of high level microwave signals. This study is being performed in cavities. It is planned to measure the electron density buildup as a function of power and gas pressure, and to determine the effects of H_2O, NO and other possible electron robbers on the density buildup.

The second phase is an investigation of the elastic collision cross sections for atmospheric and exhaust gases with low energy electrons. This program has been supported first by Western Development Division of the Air Force under Contract No. AF 19(604)-113, and now under the contract listed above. To date, measurements have been made on helium (to calibrate the measuring technique) and water vapor. The water vapor measurements cover the range from room temperature to approximately 0.8 of an electron volt. Our data on helium are in close agreement with those obtained by Gould and Brown of MIT (P_c = 18.9 cm^{-1} $(mm\ Hg)^{-1}$ as opposed to 18.3 by MIT results). Our data on water vapor give a value of P_c = 2500 cm^{-1} mm^{-1} at room temperature and indicated, as predicted by Altschuler, that Qv^2 = constant. Altshuler predicted that this should be equal to 6.0 cm^4 sec^{-2}. Our results give the value of 8.4 ± 1.0 cm^4 sec^{-2}. These data are being obtained by measuring the line width in gauss between the inflection points of the electron-cyclotron resonance absorption line for electrons diffused into a waveguide cell containing the gases to be studied.

The electrons are produced in a discharge in helium. They diffuse down a drift tube and enter the waveguide measurement cell through a tiny hole. The helium discharge and the waveguide cell each has its own vacuum system and are essentially separated. The gas to be studied flows into the measurement cell and remains undisturbed, since only thermal charged particles are present. This avoids excitation, dissociation, or creation of metastables. A solenoid provides the steady magnetic field. A small 1000-cycle magnetic field is superimposed on this to modulate the resonance line slightly about its equilibrium value. This amplitude modulates the microwave measuring field and the modulation is detected by a narrow band 'lock-in' detector. The steady magnetic field is slowly swept through the line and the output of the 1000-cycle detector is plotted against magnetic field strength. This gives a representation of the first derivative of the cyclotron resonance absorption line, and the maxima are the inflection points. The microwave measuring field is kept very small to avoid disturbing the electron energy distribution. The waveguide cell can be heated in an oven if changes in gas temperature are desired.

The technique will now be applied to nitrogen, oxygen and NO and it is hoped to measure other polyatomic gases of interest. The present contract with AFCRC terminates in June by which time the measurements on O_2, N_2 and NO should be completed.

Some consideration has been given to measurements of the elastic collision (G-factor fractional energy loss for collision by an electron) using much the same apparatus now being used. Cross sections would be measured as a function of externally controlled gas temperature and as a function of the microwave field strength. It is expected that this would give values of the G-factor of better than 50 per cent accuracy. It would appear that this would be of interest in studies of the thermalization process. It also appears that microwave techniques may be applied to measurements of electron attachment. Two possible techniques have been examined in a preliminary way. The first of these involves a measurement of the electron density of a magnetically confined plasma beam diffused down a long tube. Since transverse diffusion and recombination could be markedly reduced as loss mechanisms by proper choice of gas pressure and charge density, a measurement of the electron density as a function of distance along the drift tube will allow computation of the attachment rate. This measurement could be performed with a movable probe or movable microwave cavity which would slide down a long drift tube An alternative method would be to measure absorption at the ion cyclotron frequency associated with the ion formed by attachment. This could be done at a low enough pressure to see the resonance lines at relatively low ion density. The use of a pulsed electron source should eliminate ions produced by a discharge or other production mechanisms.

The experiments outlined are tentative ones.

UNIVERSITY OF TEXAS

At the University of Texas, Electrical Engineering Research Laboratory, Dr. A. W. Straiton is making direct measurements of the radiation effects on the refractive index of various gases, including air, using, at present, a 400-mc refractometer and a Cobalt^{-60} source. The technique employed is similar to that described by Crain in Journal of Applied Physics, November 1958, except that greater sensitivity (of the order of 10^2 to 10^3 electrons per cc at pressures of less than 0.01 atmosphere) is possible.

UNIVERSITY OF WASHINGTON

Recent and Projected Studies in Gaseous Electronics under Professor Geballe.

1. Ionization and Attachment Coefficients [1,2]

Measurements of pre-breakdown ionization currents in a number of gases have permitted the determination of ionization and attachment coefficients under circumstances when both are occurring. The measurements have been made under steady-state conditions and also, in the case of oxygen, under transient conditions, in uniform electric fields at pressures in the range of tens of millimeters of mercury. For oxygen, the attachment coefficient is now known over a considerable range of mean electron energy from about one to seven electron volts. In air, SF_6, CCl_2F_2 and a few others, it is known over a somewhat more restricted range. The process of dissociative attachment has been demonstrated to account reasonably for the magnitude of the attachment coefficient in oxygen and air, and is also held responsible for the observed attachment coefficient in other gases.

2. Energetics of Negative Ion-Forming Reactions in Oxygen [3]

The kinetic energies of ion fragments formed by electron bombardment of oxygen have been studied with an electron beam with a well-defined energy and a mass spectrometer with a specially constructed ion source. The shape and location of the cross section for dissociative attachment have been verified. Analysis of the kinetic energies of ions formed by this process and those formed through the process of ion pair production lead to values for the electron affinity of atomic oxygen in substantial agreement with the results of photo-detachment studies. Details of the distribution of ion kinetic energies found with electron energy in excess of 17 electron volts provide evidence for the existence of repulsive potentials of O_2 having a common limit for dissociation into O^+ and O . Other molecules will be studied with this apparatus.

3. Reactions of Negative Ions in Oxygen[4]

The afore-mentioned transient ion currents in oxygen[2] have shapes which can be explained successfully by postulating that the initially formed O^- is converted into O_2^- and another species, perhaps O_3^- by collision with ambient O_2 at energies of a few tenths of an electron volt. Drift velocities of these species, and also of O_2^+ have been measured and reaction coefficients have been computed. The mass spectrometric work[3] also provides evidence for the conversion of O^- to O_2^-, possibly through an ion-atom exchange reaction. This reaction will be studied further.

4. Beam Studies of Dissociative Recombination

Apparatus is being constructed to study the dissociative recombination of electrons with various molecular ions, including H_2^+, O_2^+, N_2^+ and NO^+. A beam of electrons with well-defined energy will collide with a mass-analysed ion beam from a discharge source. The electron beam will be modulated to create a favorable signal-to-noise ratio. Products will be detected with devices suitable to their particular nature.

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WESTINGHOUSE RESEARCH LABORATORY

At the Westinghouse Research Laboratory, Dr. M. A. Biondi and his group are engaged in an extensive research program to study the impact phenomena of electrons and atmospheric gases at both high and low pressures. Emphasis is being placed on studies of collision processes effective in electron depletion in the upper atmosphere. These studies include investigations of electron attachment to oxygen molecules, and elastic and inelastic collisions of electrons in nitrogen and in oxygen. As part of their longer-range effort, they are building equipment for mass analysis of neutral and ionized molecules present in a microwave afterglow to permit quantitative measurements of electron-ion recombination and of complex ion formation in atmospheric gases. In addition, they are also studying the effect of anomalous collision frequencies on the refractive indices of gases. They are also trying to reconcile the results obtained from beam experiments and swarm experiments.

Recent drift tube measurements of the attachment of low-energy electrons to oxygen is reported in Research Report 403FD317-R1, 'The Attachment of Slow Electrons in Oxygen' by L. M. Chanin, A. V. Phelps, and M. A. Biondi, dated November 6, 1958. Results published in the report indicate that the attachment consists of two separate processes--a pressure-independent two-body process, for $\frac{E}{p} > 2$, and a pressure-dependent three-body process for $\frac{E}{p} < 2$. Results for $2 < \frac{E}{p} < 10$ give an attachment cross section increasing with average electron energy with a value of $\sigma \simeq 2 \times 10^{-19}$ cm^2 at an estimated electron energy of 3 electron volts. However, at low $\frac{E}{p}$ their data show a three-body pressure dependence giving an attachment rate more than 100 times the thermal value deduced from their earlier microwave measurements.[1] These measurements extended down to $\frac{E}{p} = 0.07$, and give the three-body coefficient for the reaction for electrons of energy 0.09 electron volt to be 5×10^{-30} cm^6/sec; however, more recent unpublished data for lower electron energies indicate that the attachment coefficient for the three-body process decreases at lower electron energies, perhaps to a value of 10^{-30} cm^6/sec, which would be consistent with microwave data. They plan to conduct further experiments at lower energies with a new, shorter drift tube, and with gas cooled to liquid nitrogen temperatures. They state that any residual disagreement with microwave measurements probably can be attributed to the fact that in microwave experiments some of the molecules may be in excited states that may cause detachment, and therefore make the cross section look lower. Microwave measurements are presently being conducted at Westinghouse in an attempt to clarify this point. Future plans call for installing a mass spectrometer to detect the ions formed in a microwave cavity when a breakdown has been induced by microwave energy from a high-powered magnetron. A report, 'Afterglow Study of the Dissociative Recombination of Molecular Ions and Electrons' by W. A. Rogers, tells of some of the work they have done in this field.[2]

Further measurements of the attachment cross section in O_2 by electrons are being made by G. J. Schulz. An electron gun using the retarding potential difference method for production of electrons in an effective energy range of 0.1 to 0.2 ev ejects electrons into a collision chamber.[3] The cross section for production of O^- as a function of electron energy by dissociative attachment to O_2 has been measured and is in agreement in both shape and value with the results published by Craggs, Thorburn and Tozer[4] up to electron energies of about 9 electron volts. Several possibilities for experimental error need to be investigated before the data will be published. Modification of the experiment is underway to permit studies at high pressures (approximately 1 mm) and lower energies (down to approximately 0.1 ev). With these changes they plan to use electron beam techniques to study the three-body attachment process previously investigated with swarm experiments.

Dr. Schulz has also been studying the inelastic collisions of electrons and molecular gases using the trapped electron method.(5) He has studied the energy loss processes of electrons in N_2, H_2, and O_2. Electrons of known energy are ejected into the collision chamber. Those electrons, which have undergone an inelastic collision, and therefore lost a portion of their initial energy, are trapped in a potential well which prevents their escape to the electron beam collector. At present, the potential well can be varied from zero to 3 volts. Future plans call for remaking the experiment so that larger trap depths may be achieved. He also plans to make a longer tube which will give him better trap resolutinn. A paper describing this experiment has been published in the Physical Review.(6)

J. L. Pack and A. V. Phelps are making measurements of electron drift velocity in atmospheric gases. The techniques and apparatus used to measure drift velocity of electrons in helium and hydrogen have been applied to electrons in N_2 and O_2.(7) The object of these studies is to extend the measurements of electron drift velocity to low $\frac{E}{p}$ so that electrons are essentially in thermal equilibrium with a gas. Such information is essential for the calculation of attachment frequencies and cross sections from measured attachment coefficients. Modification of the apparatus is currently underway to substitute a pulsed UV light source for one of the grids normally used to control the flow of electrons in the drift tube. This should increase the sensitivity of the apparatus at low $\frac{E}{p}$. Measurements in oxygen are made difficult because of its large attachment cross section. The proposed modification, which eliminates some of the drift region, is expected to improve the accuracy of the method for electronegative cases.

Dr. Lee Frost is doing theoretical work calculating electron energy distribution functions in molecular gases.

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YALE UNIVERSITY

At Yale University, Dr. Margenau has made theoretical calculations of the real and imaginary parts of the conductivity of ionized air in the microwave bands. This is a continuation of work which he has already published (Phys. Rev. 109, 6-9, Jan. 1, 1958; and 108, 1367-1371, Dec. 15, 1957). The work is summarized in a paper (Margenau, Desloge, and Stillinger, "Microwave Conductivity of Slightly Ionized Air"), presented in Moscow this year. Part of this paper will be published in English (Phys. Rev., probably Dec. 1958), and it is all to be published in Russian.

This work is an attempt to calculate microwave conductivities of air at sea level, 50,000 ft, and 100,000 ft from experimentally determined collision cross sections of oxygen and nitrogen.

Two problems have been considered:

1. The conditions of validity of a formula for the microwave conductivity of a plasma (H. Margenau, Phys. Rev. 109, 6, 1958) have been examined. The reason why theory can lead to negative real parts of the conductivity is traced to the neglect of higher terms in the expansion customary in this analysis. Also a simpler derivation of the formula and an alternate result have been given.

2. The conductivity of air has been computed with the use of experimentally established collision cross sections of electrons in oxygen and nitrogen. The calculation is not yet sufficiently realistic to be applicable to high temperature conditions where ionization of the constituents of the atmosphere occurs. However, it indicates the departures to be expected from predictions that have been made on the basis of the usual simplifying assumptions: (a) that the time between collisions is constant; (b) that the mean free path of the electrons is constant. In case (a) the Lorentz formula is valid.

While usually reliable for estimates of conductivity, the errors it entails are much greater than present errors of measurement. The frequency of maximum absorption is determined as a function of the electron temperature and is found to differ considerably from the values estimated by either of the approximate methods at the higher temperatures. The next phase of this work is a classified application dealing with conductivity.

Professor Margenau is also interested in work on cyclotron resonance and line broadening (see Margenau and Landwehr, "The Structure of Spectral Lines Emitted from Plasmas," prepared under Air Force Contract AF-18(603)-15). More work in this field is being planned for the future.

Also at Yale, Dr. Oster is just starting theoretical work on cyclotron resonance. Dr. Desloge is continuing work on the conductivities of rarefied plasmas by trying to include electron-electron and electron-ion collisions in addition to the electron-atom collisions that have already been studied. Dr. Mintzer is making similar calculations for more dense plasmas, using magneto-hydrodynamic theory instead of a particle theory. All of this work is just beginning.

UNCLASSIFIED

UNCLASSIFIED